

## SPONTANEOUS IGNITION CHARACTERISTICS OF HYDROCARBON FUEL-AIR MIXTURES

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Although the subject of spontaneous ignition of liquid fuels has received considerable attention in the past, the role of fuel evaporation in the overall spontaneous ignition process is still unclear. A main purpose of this research is to carry out measurements of ignition delay times, using fuels of current and anticipated future aeronautical interest, at test conditions that are representative of those encountered in modern gas turbine engines. Attention is focused on the fuel injection process, in particular the measurement and control of mean fuel drop size and fuel-air spatial distribution. The experiments are designed to provide accurate information on the role of fuel evaporation processes in determining the overall ignition delay time. The second objective is to examine in detail the theoretical aspects of spontaneous ignition in order to improve upon current knowledge and understanding of the basic processes involved, so that the results of the investigation can find general and widespread application.

### Experimental

The first phase of the experimental program, which has just commenced, will utilize gaseous fuels only; namely propane and vaporized Jet A fuel. Its purpose is to determine accurately ignition delay times under conditions where a value of zero can be assigned to the fuel evaporation time. The tests will be conducted over a range of pressures from 1 to 10 atmospheres at unvitiated air inlet temperatures up to 900K. In some tests the oxygen content or nitrogen content of the main air stream will be varied in order to ascertain the effect of O<sub>2</sub>/N<sub>2</sub> ratio on chemical delay time. The information provided in these tests will be utilized in developing the theoretical model for spontaneous ignition. The test rig employed is shown schematically in Figure 1. The test section is constructed from several lengths of 30 mm dia. stainless steel tubing to form a maximum total length of 1 meter. Multipoint fuel injection is employed to ensure that the fuel-air mixing time is always negligibly small in relation to the ignition delay time. The test section is water-cooled to eliminate the possibility of flashback occurring along the boundary layer adjacent to the duct wall. It is proposed to use the same test procedure as that used successfully by Spadaccini and Te Velde (1). It consists of establishing prescribed conditions of pressure and fuel and air flow rates and gradually increasing the inlet air temperature until autoignition occurs at the exit of the test duct. The occurrence of autoignition will be detected by thermocouple probes located at the duct exit and by photodetectors located at several positions in the test rig.

### Theoretical

Considerable progress has been made in simplifying and shortening the procedures involved in the calculation of fuel spray evaporation times. In a previous study by Rao and Lefebvre [2] the evaporation time was obtained as:

$$t_e = \frac{\rho_f c_{p_a} D_{32}^2}{8 k_a \ln(1+B)} \left[ \frac{1 - \left( \frac{1-f}{1-\Omega} \right)^{2/3}}{1 + 0.25 \text{Re}_{D_{32}}^{0.5}} \right] \quad (1)$$

where       $B$       = mass transfer number  
 $D_{32}$       = Sauter mean diameter, m  
 $\text{Re}_{D_{32}}$       =  $u' D_{32}/v_a$   
 $f$       = fraction of fuel in vapor form  
 $k_a$       = air conductivity, J/ms K  
 $c_{p_a}$       = air specific heat, J/kg K  
 $u'$       = rms value of fluctuating velocity  
 $\rho_a$       = air density, kg/m<sup>3</sup>  
 $\rho_f$       = fuel density, kg/m<sup>3</sup>  
 $\Omega$       = fraction of fuel initially in vapor form  
 $v_a$       = air viscosity, m<sup>2</sup>/s

A drawback to the above equation is that it assumes a constant value of  $B$  for the entire evaporation period. However,  $B$  is constant only for steady-state evaporation. During the heat-up period the value of  $B$  rises continuously from an initial low value up to the steady-state value. Thus, in practice, the value of  $B$  for insertion into Eq. (1) should be lower than the steady-state value by an amount that depends on the ambient air pressure and temperature, and on the boiling temperature of the fuel.

To overcome this deficiency the mass transfer number,  $B$ , is replaced by the evaporation constant,  $\lambda$ , using the relationship

$$\lambda = \frac{8 (k/c_{p_a}) \ln(1+B)}{\rho_f} \quad (2)$$

Substituting for  $\ln(1+B)$  from Eq. (2) into Eq. (1) gives

$$t_p = \frac{D_{32}^2}{\lambda_{\text{eff}}} \left[ 1 - \left[ \frac{1-f}{1-\Omega} \right]^{2/3} \right] \quad (3)$$

where  $\lambda_{\text{eff}}$  is an "effective" value of  $\lambda$  which takes into account both convective effects and the reduced evaporation rate during the heat-up period. Values of  $\lambda_{\text{eff}}$  have been calculated for liquid hydrocarbons ranging in normal boiling temperature from 420 to 560 K, evaporating in air at temperatures and pressures up to 2000 K and 2000 kPa respectively. Some typical values of  $\lambda_{\text{eff}}$  are given in Figure 2 for a gas pressure of 2000 kPa.

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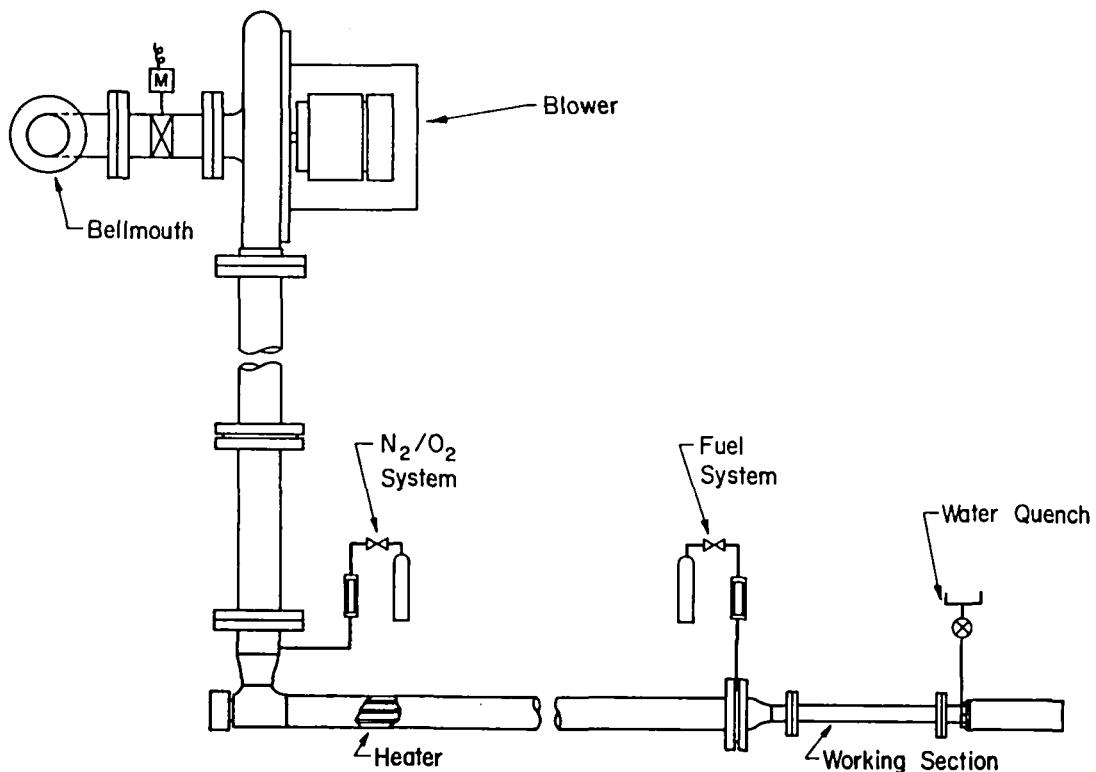


Figure 1. Schematic Diagram of Test Rig.

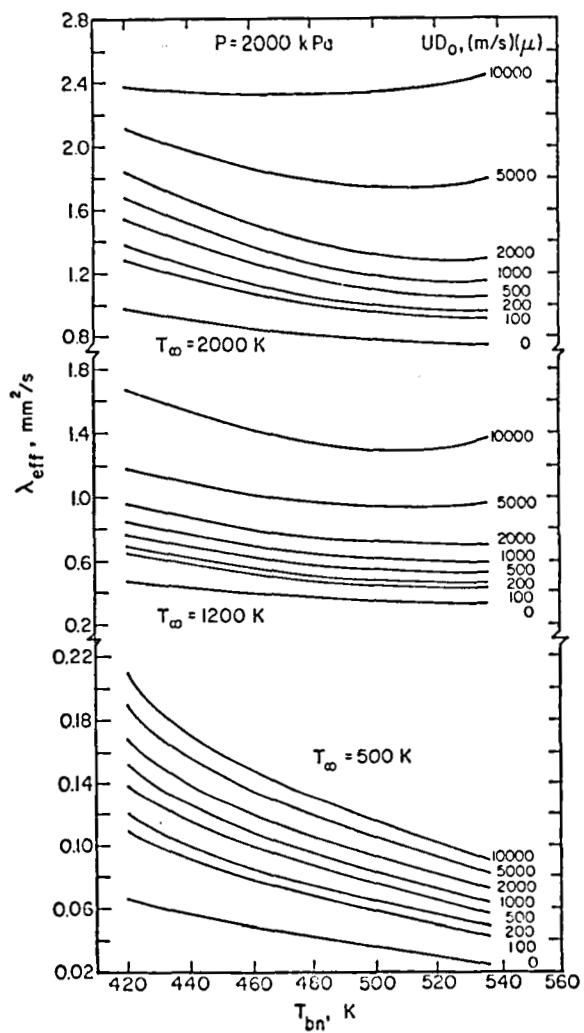


Fig. 2. Variation of effective evaporation constant with normal boiling point at a pressure of 2000kPa.